Conservation tillage has a very direct effect on the rate at which atmospheric carbon is sequestered in cropland soils. In an Indiana study, intensive tillage stored 0.042 tons (84 pounds) of carbon per acre, moderate tillage sequestered 0.169 tons (338 pounds) per acre, and no-till stored 0.223 tons (446 pounds) of carbon per acre annually (Smith et al., 2002). According to Feng et al. (2000), conservation tillage and residue management could account for 49 percent of the carbon sequestration potential of U.S. cropland. Switching from conventional tillage to no-till in a corn-soybean rotation in Iowa has been estimated to increase carbon sequestration by 550 kg/ha (485 lb/a) per year (Paustian et al., 2000).

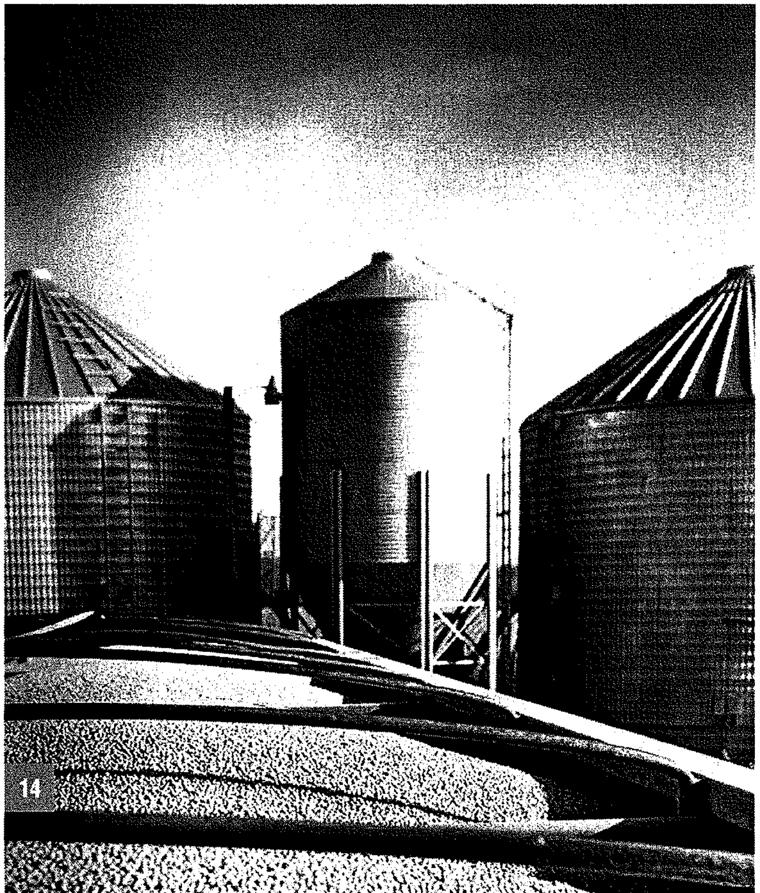
The power of no-till to build soil organic matter and sequester carbon was documented by Reicosky and Lindstrom (1995), who measured that a single pass with a moldboard plow in a field of wheat stubble released five times as much carbon dioxide over 19 days as was released from untilled plots.

Because even a single tillage pass can aerate the soil and stimulate microbial activity that returns a significant amount of the soil organic carbon to the atmosphere as CO_2, continuous no-till – maintaining no-till practices throughout the crop rotation – is the most effective way to maximizing the carbon sequestration potential of the soil. Using a conservative assumption that an acre of continuously no-tilled cropland sequesters 0.6 metric tons of carbon dioxide equivalent (the standard measure of carbon sequestration) per acre per year, it is estimated the 16.3 million acres of continuously no-tilled cropland in the U.S. is currently sequestering 9.7 million tons of carbon dioxide equivalent each year (CTIC, 2009).

Reduced emissions. Conservation tillage has an even more direct impact on greenhouse gas levels. It can reduce the number of trips needed to produce a crop and lowering the horsepower requirement for crop production, it reduces the amount of fuel used in farming. Mulch tillage – light to moderate tillage passes that leave more than 30 percent residue cover after planting – saves approximately 2.0 gallons per acre (Jasa et al., 2000). Across the 46.7 million acres of mulch-tilled cropland, that represents a savings of 93.4 million gallons of diesel. Jasa et al. (1991) figured the advantage of no-till over moldboard plowing

Soybeans: Valuable Rotation Crop

Technology that encourages the use of soybeans in a crop rotation provides growers with a powerful tool for improving yields and managing pests. Beyond their ability to fix atmospheric nitrogen in the soil, soybeans can also enhance the yield of subsequent crops by leaving soil moisture in place for the following crop, interrupting pest and disease cycles, supplying chemical compounds that may enhance the health or growth of other crops, and improving the microbial community in the soil (Swink et al., 2007).



Making a Great Biofuel Source Even Better

Soybeans are an important source of biofuel feedstock. Producing soybeans in conservation tillage systems improves the carbon footprint of the process significantly; future biotech varieties may also contribute further.

An important and controversial metric in assessing the environmental impacts of biofuels vs. fossil fuels is the "payback period," the length of time required for biofuels to overcome the "carbon debt" of greenhouse gases released due to changes in land use related to producing the biofuel feedstock. The normal payback period for biofuels has been estimated at 100 to 1,000 years, depending on the ecosystem affected by the land use change; however, no-till or no-till/cover crop systems can reduce the payback period to three years in the case of payback for grassland conversion or 14 years if called upon to pay back for the conversion of forest (Kim et al., 2009).

to be a fuel savings of 3.9 gallons per acre. Extrapolating that out over the nation's 65 million acres of no-till crops, a savings of 253.5 million gallons of diesel is realized. Combining those two figures, conservation tillage saves 353.8 million gallons of diesel per year.

Kern and Johnson (1993) determined no-till could reduce fuel consumption by 3.5 to 5.7 gallons per acre, depending on the number and type of tillage trips eliminated, the soil type and moisture content.

Calculations by the Western Environmental Law Center estimate diesel agricultural tractors contribute 17.11 percent of the CO_2 emissions from nonroad vehicles and engines in the U.S., so reducing tractor passes has a direct effect on national greenhouse gas output (Western Environmental Law Center, 2007).

According to the U.S. EPA, every gallon of diesel represents 22.2 pounds of carbon dioxide emissions (U.S. EPA, 2005). Applying that figure to the 353.8 million gallons of diesel saved by reducing or eliminating tillage, conservation farmers lower carbon dioxide emissions by 3.92 million tons per year through fuel savings alone. If, in the year 2020, 90 percent of the nation's soybeans were herbicide-tolerant varieties and 80 percent of the crop was planted no-till, the combination of biotechnology and no-till farming would reduce soybean farmers' carbon dioxide emissions by 2.3 million tons.

Reducing tillage passes also saves farmers time and money. Eliminating an average of 2.5 tillage trips per year in a corn/soybean rotation on a 2,000-acre operation would reduce on-farm labor by 600 hours each year. Tractors would last longer because they were not being used for the hard duty of pulling heavy tillage implements through the soil, and equipment costs could be lowered because the number, horsepower requirements and annual hours of service of tractors can be reduced.

Less fertilizer. Soybeans play an important role in reducing the need for nitrogen fertilizer, which is typically manufactured from fossil fuel, and can release nitrogen oxides under certain conditions after application. Soybean plants fix atmospheric nitrogen in the soil through their relationship with bacteria that live in nodules on their roots.

The amount of nitrogen captured from the air and fixed in the soil by soybean crops can be substantial. Varvel and Wilhelm (2003) determined that corn planted after soybeans obtained 65 kg/ha (58 lb/a) of

nitrogen from the soybean crop, and sorghum in a sorghum-soybean rotation received an 80 kg/ha (71 lb/a) nitrogen fertilizer replacement value from the prior year's soybeans. Swink et al. (2007) conducted an extensive literature review, finding nitrogen fertilizer replacement values (NFRVs) from soybeans ranging from 0 to 188 lb/a. They also found evidence that nitrogen mineralization rates in corn peaked both higher and earlier after soybeans than after corn (Swink et al., 2007).

The University of Nebraska recommends allowing a 45-pound-per-acre nitrogen credit in corn following soybeans; the University of Illinois calculates a nitrogen fertilizer replacement value of 40 pounds per acre after a soybean crop. Using a conservative NFRV of 20 to 30 pounds of nitrogen following soybeans – to recognize the variation in effect across climates and soil types – soybeans on 73 million acres of U.S. cropland in 2008 supplied 2.9 to 3.7 million pounds of nitrogen for possible use by subsequent crops.

The use of soybeans in rotation, more precise rates and application of fertilizer, and other agronomic practices that minimize the rates and loss of nutrients can be a highly cost-effective approach to reducing greenhouse gases.

Evolving Incentives for Reducing Greenhouse Gases

Society has expressed a growing interest in reducing levels of atmospheric carbon and other greenhouse gases. Costs or benefits to society that do not accrue to parties engaged in a market transaction are called externalities. In the case of soil carbon sequestration, externalities may include the conservation of soil nutrients, fossil fuels, water quality, wildlife habitat and biodiversity. In fact, carbon sequestration is best viewed as part of a package of environmental benefits, according to Tweeten et al. (2000). Researchers have calculated a wide range of values for the externality costs of soil erosion, a spectrum that extends from $500 million to $7 billion per year (Tweeten et al., 2000).

The value of the externalities associated with carbon sequestration and conservation tillage can help society set a price on the greenhouse gas-reducing services agriculture can provide.

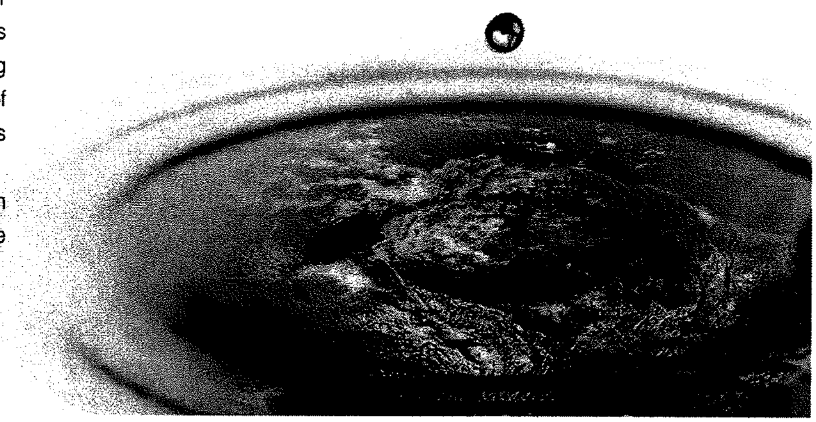
As society seeks solutions to elevated levels of greenhouse gases in the atmosphere, lawmakers may create larger incentives for adopting conservation farming practices. Greater funding for cost-share programs that help make BMPs, such as conservation tillage, more attractive can have a large impact on the adoption of conservation practices. So can a strong market for carbon credits, which allow emitters of greenhouse gases to pay farmers to offset those emissions through the use of BMPs such as those mentioned above. Selling carbon credits for their sequestration services could provide U.S. farmers with a steady, long-lasting revenue stream and could provide the country with inexpensive, easily enabled tools to begin lowering greenhouse gas emissions.

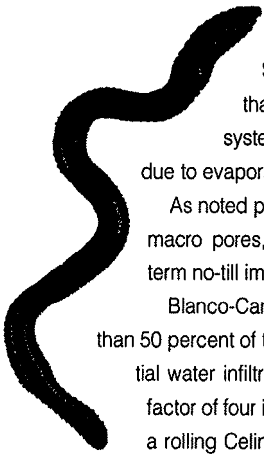
In either case, biotech crops will play a significant role in reducing agriculture's carbon footprint – and America as a whole – by facilitating the adoption of conservation farming practices.

Conserving Water

Conservation tillage and no-till conserve water in several ways, primarily by minimizing evaporation and improving infiltration. Soils improved by years of conservation tillage also have greater water retention capacity due to their increased levels of soil organic matter.

Tillage exposes moist soil to the atmosphere, releasing moisture through evaporation. Each tillage pass reduces soil moisture by the equivalent of 0.5 inches to 1.0 inch of rainfall. In Kentucky, annual evaporation was reduced by 5.9 inches in a no-till system (Siemans, 1998).





Several South American studies have indicated that crop residue left on the soil surface in no-till systems results in a reduction in surface soil water loss due to evaporation of up to 30 percent (Damalgo et al., 2004).

As noted previously, the formation of healthier soil structure, macro pores, cracks and earthworm burrows through long-term no-till improves infiltration of water into the soil.

Blanco-Canqui and Lal (2007) observed that removing more than 50 percent of the corn stover from the soil surface reduced initial water infiltration rates – measured for the first hour – by a factor of four in a hilly Rayne silt loam and by a factor of two on a rolling Celina silt loam soil, noting the unprotected soil was more prone to crusting and had fewer surface-connected earthworm burrows than residue-protected soils.

Water that infiltrates into the soil rather than running off into ditches and streams is more likely to be available to the crop later in the season. That can be important in dry years or semi-arid areas, and will grow ever more critical as pressure mounts to manage every acre to produce its maximum potential yield.

When water follows its natural pathway of infiltrating into healthy soil rather than flowing across the soil surface in gully-like rills or broad sheets, it flows to the water table and feeds rivers and streams through subsurface flow. That water is filtered by the soil through which it passes, and the rate of its introduction to the stream is moderated by hydraulic pressure in the ground. If the adoption rate of conservation tillage and other BMPs is high enough, the result can be cleaner water and potentially less dramatic flood events compared to replenishment by surface flow.

An Ohio study compared the total water runoff from a 1.2 acre area with a 9-percent slope that had been continuously no-tilled with a similar test area that had been conventionally tilled. Over four years, runoff was 99 percent less where long-term no-till had been practiced (Edwards et al., 1989). The authors attributed the vast difference in infiltration to the development of macro pores in the no-tilled soils.

In a study of the Pecatonica River in Wisconsin, Potter (1991) documented a decrease in winter/spring flood peaks and volumes, as well as an increase in base flow from infiltration of water into the river. He attributed the reduced flooding to the adoption of conservation tillage in the area, noting that there were no major land-use changes, new reservoirs or weather events to correlate with the observation.

U.S. Conservation Tillage by Crop*

Crop	*Total Acres Million*	*No-till Million acres*	*Mulch-till Million acres*	*Conservation tillage total*
Corn	83.1	17.4 (21%)	14.8 (18%)	33.4 (40%)
Soybeans	72.9	30.1 (41%)	15.3 (21%)	46.0 (63%)
Winter Wheat	44.0	6.4 (15%)	6.1 (14%)	12.5 (29%)
Grain Sorghum	8.5	1.7 (20%)	0.95 (11%)	2.7 (32%)
Cotton	13.5	2.4 (18%)	0.25 (22%)	2.9 (21%)
Spring Grains	27.1	4.5 (17%)	6.1 (27%)	10.7 (39%)
Forages	7.4	1.0 (14%)	0.84 (11%)	1.9 (25%)
Other Crops	17.6	1.5 (8%)	2.1 (12%)	3.7 (21%)
TOTAL	274.2	65.0 (24%)	46.5 (17%)	113.8 (42%)

Source: 2008 National Crop Residue Management Survey, Conservation Technology Information Center
2004 data for most states/counties (2006 for Illinois, some counties in Missouri and Nebraska; 2007 for Indiana and some counties in Virginia and Minnesota; 2008 Iowa (2/3 of counties).
*Conservation tillage has more than 30% residue left on the soil surface after planting and is the sum of no-till, much-till and ridge-till acres. Ridge-till acres are less than 1% of all cropland and are not listed individually but are included in conservation tillage acres. Number may not total 100% due to rounding.

Water Quality Trading Opportunities

As with carbon credits, water quality credits could become a marketable commodity for many U.S. farmers. In an effort to reduce nutrient loading in rivers and lakes, many states allow municipal and industrial dischargers to offset their emissions with purchased water quality credits. Erosion-reducing BMPs such as conservation tillage allow farmers to provide effective water quality services at a fraction of the cost of facility upgrades or other options.

For instance, the Miami Conservancy District in Dayton, Ohio, estimated water quality treatment plant upgrades needed to bring a local watershed into compliance with water quality regulations would cost $23 per pound of phosphorus. By contrast, the average unit cost of phosphorus reduction by converting farmland to no-till was estimated at $1.08 – and even though costs of agricultural BMPs rose to $1.29 during the district's pilot trading project, they still represent a significantly more cost-effective approach to removing phosphorus from the system (U.S. EPA, 2008). During the course of the pilot program, farmers in the Great Miami watershed reduced waterborne nitrogen and phosphorus by 434,000 pounds (U.S. EPA, 2008).

Similarly, the city of Cumberland, Wis., contracted to pay area growers $18.50 per acre to convert to no-till farming as part of its water quality trading program to reduce phosphorus in the Red Cedar River (CTIC, 2006), and removed 31,500 pounds of phosphorus under the program by 2004 (U.S. EPA, 2008).

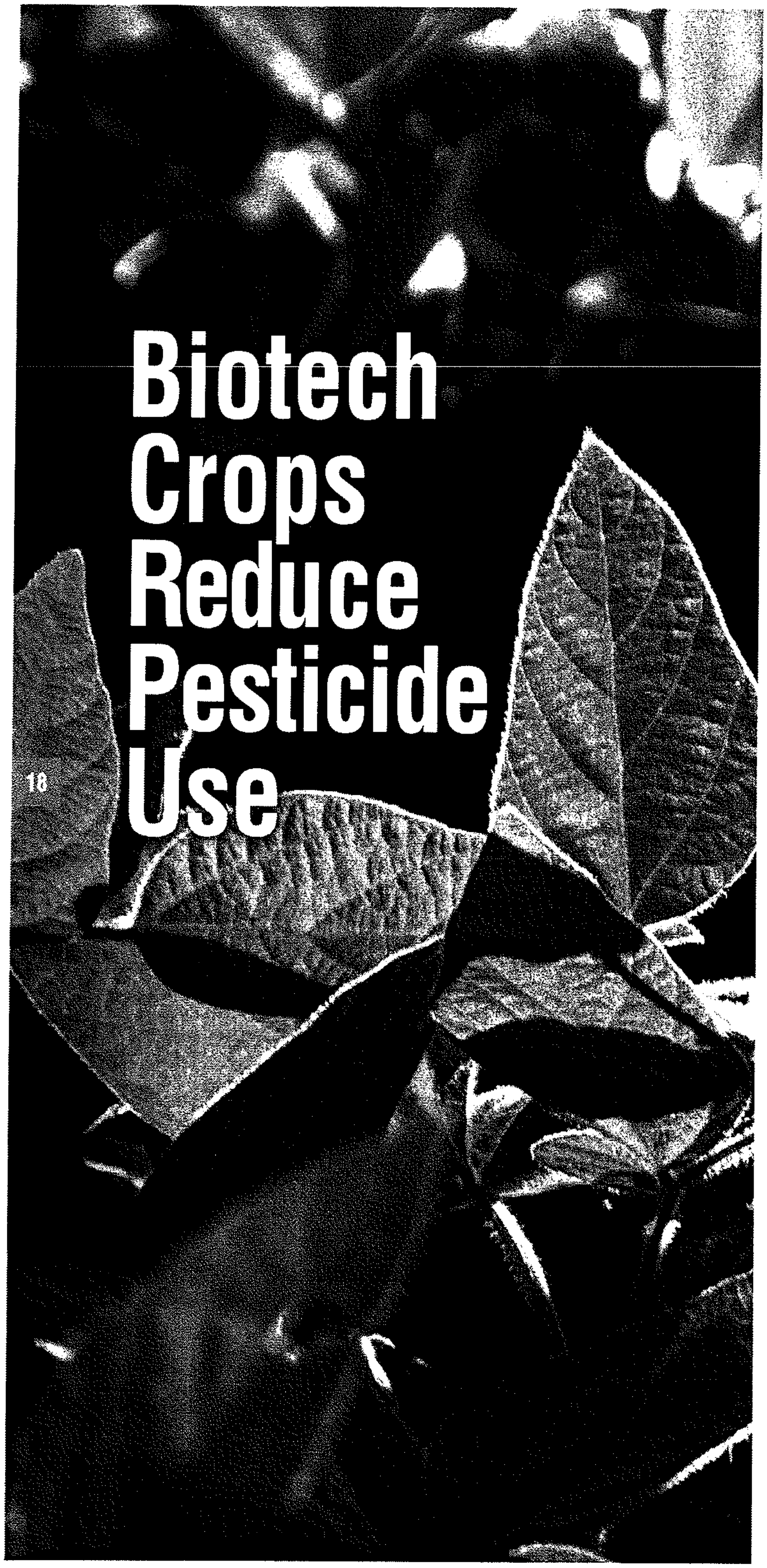
Like the market for carbon credits, water quality trading programs remain a work in progress, subject to the evolution of frameworks that create fungible instruments, verifiable results, and viable marketing systems, as well as regulations that could strengthen demand and prices for the services farmers provide. As society continues to demand effective solutions to air and water pollution, these mechanisms are likely to mature, with farmers likely to be paid for their environmental services as well as the food and fiber they produce.

Improving Wildlife Habitat

Conservation tillage and no-till provide far superior habitat for an array of animals, including insects and the birds that feed on them. Reducing the disturbance of residue in the top few inches of the soil favors the survival of ants, spiders, ground beetles and rove beetles that often feed on other insects, including pests (Barnes, 2006). In turn, the insects provide sustenance for an array of birds and other animals that thrive in the low-disturbance environment of a no-till field.

Palmer (1995) found that bobwhite quail chicks in North Carolina needed 22 hours to obtain their minimum daily requirement of insects in conventional soybean fields. In no-till soybean fields, the chicks needed just 4.2 hours to obtain their minimum requirement. That was roughly the same amount of time the chicks needed to sustain themselves in natural fallow areas believed to be ideal quail habitat, where it took 4.3 hours.

Biotech Crops Reduce Pesticide Use



Among the most attractive benefits of many early biotech crops – from a grower perspective as well as an environmental one – is their built-in ability to combat pests such as insects or pathogens, or to allow producers to use highly effective products to fight weeds. The net result is not just more grower-friendly crops, but also a reduction in the cost of production and the use of crop protection chemicals.

Combating Weeds

Weeds are the leading challenge for soybean growers worldwide, causing more yield loss than either insects or diseases (Heatherly et al., 2009; Oerke, 2006). Oerke (2006) estimates global yield loss to weeds at 37 percent. The development of herbicides in the latter half of the 20th century replaced time- and tillage-intensive mechanical weed control with management-intensive chemical control.

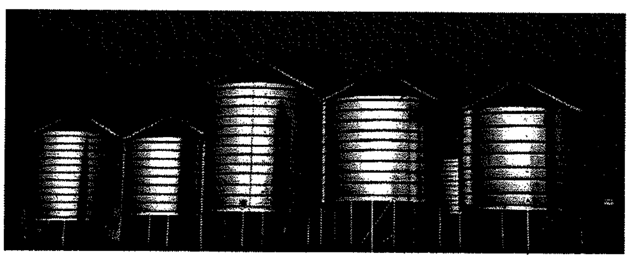
Herbicides brought challenges of their own. The efficacy of available herbicides on specific weed species caused shifts in the population dynamics of weeds, with less-adequately-controlled species increasing in dominance until other herbicides or mechanical weed control were introduced. Many persistent soil herbicides, used for decades on millions of acres of cropland each year, found their way into streams and groundwater.

Targeting, timing and application also require knowledge and skill. By 1996, the year glyphosate-tolerant soybeans were introduced to the marketplace, 27 different herbicidal active ingredients representing nine distinct modes of action, each with its own strengths and weaknesses, were registered for use in U.S. soybeans (Heatherly et al., 2009). By contrast, planting Roundup Ready soybeans allowed growers to apply glyphosate, the active ingredient in Roundup and several other herbicides, as a broadcast post-emergence spray to control a broad spectrum of weeds in one or two applications.

Glyphosate is a remarkable herbicide, both in its efficacy and its environmental profile. When it comes in contact with plant tissue, glyphosate translocates quickly through the plant to accumulate in the

growing point. There, it inhibits the action of the 5-enolpuruvylshikimate-3-phosphate synthase (EPSPS) enzyme, which plays a vital role in the growth of plants, fungi and bacteria. Inhibited by glyphosate, the EPSPS system fails and the plants die – even perennial weeds that were extremely difficult to control with other herbicides. In fact, glyphosate is labeled for control or suppression of well over 100 weed species (Monsanto, 2007).

Ordinarily, glyphosate would also kill the crop. However, there are two EPSPS enzyme systems in nature – EPSPS 1, found in plants, fungi and some bacteria, which is susceptible to glyphosate, and EPSPS 2, a version found in some bacteria that is not inhibited by glyphosate (Shaner, 2006). To create glyphosate-tolerant soybeans, breeders used genetic transformation technology to move a gene for the EPSPS 2 system from a soil bacterium to a soybean plant. The transformed soybean line was then crossed with elite germplasm to create high-performing soybean varieties that rely on the EPSPS 2 enzyme system rather than the glyphosate-susceptible EPSPS 1 pathway.



Better Environmental Profile

According to the Extension Toxicology Network (Extoxnet, 1996), a multi-university clearinghouse for information on crop protection products, glyphosate is "practically non-toxic by ingestion," "practically non-toxic to fish," and long-term feeding studies have consistently shown no adverse effects even after two years of high-rate exposure in the diets of several animal species. The molecule is also tightly bound to soil particles almost immediately, which renders glyphosate unlikely to leach into the soil or run off in the event of rain (Extoxnet, 1996). Glyphosate also has a half-life in the environment of 47 days, compared with half-lives of 60 to 90 days for the herbicides it replaces (Heimlich et al., 2000).

Using the U.S. EPA's reference dose for humans to create a chronic risk indicator, USDA calculates that glyphosate replaces herbicides that have toxicity ratings 3.4 to 16.8 times higher (Shutske, 2005).

In addition to permitting a shift to a more environmentally benign herbicide, glyphosate-tolerant soybeans led to a significant decrease in production costs. The herbicide cost for the biotech soybean crop represented an annual savings of $1.56 billion in production costs in spite of the additional investment in technology fees for biotech seed (Johnson et al., 2007).

Weed Resistance Requires Management

Glyphosate-tolerant crops – notably soybeans and corn, which are commonly rotated with each other in the Midwest, and glyphosate-tolerant cotton in the South – are increasingly being challenged by weeds resistant to glyphosate. Once considered a remote possibility, the specter of glyphosate-resistant weeds has become a harsh reality. Horseweed (marestail) exhibiting 8-to-13-fold resistance to glyphosate emerged in a Delaware soybean field in 2000 after three years of glyphosate-only weed management (VanGessel, 2001).

Since then, certain populations of an array of weeds have exhibited resistance, including giant ragweed, common ragweed, common waterhemp, Palmer amaranth, Italian ryegrass and Johnsongrass.

Resistant weeds are not a new phenomenon, and though disappointing, resistance to glyphosate does not eclipse the cost, management and environmental benefits of glyphosate-tolerant crops. However, it does require growers to employ other weed control tools where resistant populations are present or expected. They may need to draw from the arsenal of older herbicides that are effective against the resistant weed species, or consider adding glufosinate-tolerant crops (biotech varieties marketed as Liberty Link®), or forthcoming biotech crops tolerant to such classic herbicides as dicamba or 2,4-D to their crop rotation in order to bring another mode of action into their program.

Regardless of the development of weed resistance to herbicides, the net benefits of biotech herbicide-resistant crops remain positive.

Fewer Pounds of Active Ingredient

Among the most dramatic and immediate benefits of biotech input traits was a significant reduction in the use of herbicides and insecticides.

By 2006, 90 percent of the U.S. soybean crop was planted to herbicide-tolerant soybeans. That year, soybean growers reduced their herbicide usage by an average of 0.5 pounds of active ingredient per acre, or a total of 23 million pounds nationwide, compared to conventional herbicide programs (Johnson et al., 2007). That represents a reduction of nearly one-third of the average of 1.53 pounds per acre of herbicide active ingredient applied that year in conventional soybean programs.

Herbicide-tolerant cotton varieties reduced the amount of herbicide active ingredient applied to the cotton crop by 24.4 million pounds and saved cotton growers an estimated $230 million in weed control costs (Johnson et al., 2007).

Similarly, the adoption of Bt varieties of corn and cotton led to wide-scale reductions in insecticide use. For instance, Johnson et al. (2007) calculated that YieldGard® Bt corn planted on 16.6 million acres in 2006 to combat corn borer resulted in a nationwide increase in corn production of 65.1 million bushels, for a net return of $185 million – while reducing insecticide applications by a staggering 2.87 million pounds of active ingredient. The same year, cotton growers who planted Bt cotton varieties reduced insecticide use by 1.9 million pounds of active ingredient (Johnson et al., 2007).

Following the successful introductions of cotton Bt varieties targeted at the cotton bollworm complex and corn that expressed Bt crystals toxic to several species of corn borers, other Bt proteins, or events, were introduced. Events targeted at corn rootworm – a pest that forces growers to apply millions of pounds of soil insecticides and seed treatments per year in prophylactic applications – are among the most important new Bt genes. So are Bt events designed to minimize the risk of insect resistance among target *Lepidoptera*, as well as stacks of corn borer, cutworm and rootworm Bt events such as Dow AgroSciences' Herculex® XTRA.

Johnson and his team (2007) estimated that YieldGard RW corn, a family of Bt hybrids targeted at rootworm control, delivers a 5-percent improvement in yields over conventional insecticide treatments. In 2006, they calculated the 5-percent yield improvement totaled 3.3 million pounds (58,000 bushels) of corn on 7.7 million acres planted to the YieldGard RW hybrids. On that acreage, growers would have otherwise applied 3.9 million pounds of insecticide active ingredient to control rootworms, according to the researchers.

The Role of Conservation Tillage in Reducing Pesticide Movement

Conservation tillage plays an interesting role in reducing the chances of off-target movement of crop protection products. Because of their spectrum of control and the fact that they do not require incorporation into the soil, glyphosate and other postemergence herbicides are an excellent fit in conservation tillage and no-till systems. Glyphosate also rapidly becomes deactivated by quickly and tightly binding to soil particles, which reduces leaching. Conservation tillage systems significantly reduce soil erosion, so runoff of the herbicide molecules that are tightly bound to the soil is minimized.

Conservation tillage also tends to foster high populations of earthworms (Stinner and House, 1990). Earthworm burrows are lined with mucous that has been shown to adsorb pesticides. When the herbicide atrazine was poured down nightcrawler burrows, concentrations exiting at the bottom were reduced ten-fold (Stehouwer et al., 1994). Though not all studies demonstrate that no-till reduces pesticide leaching, the practice is widely recommended by water quality specialists because many studies have shown reductions in the movement of crop protection products through the soil where no-till is used (Gish et al., 1995; Novak, 1997).

Conclusion

It has been nearly two decades since agricultural biotechnology put the ancient art of employing living organisms to produce specific products to the modern task of creating crops with novel properties – including tolerance to environmentally friendly herbicides and built-in protection from pests and diseases. In that short time, plant breeders have equipped farmers with crops that can be grown more productively and more cost-effectively to supply a growing population. No other options have been identified that offer potential benefits as great as biotech crops farmed with sustainable agricultural practices.

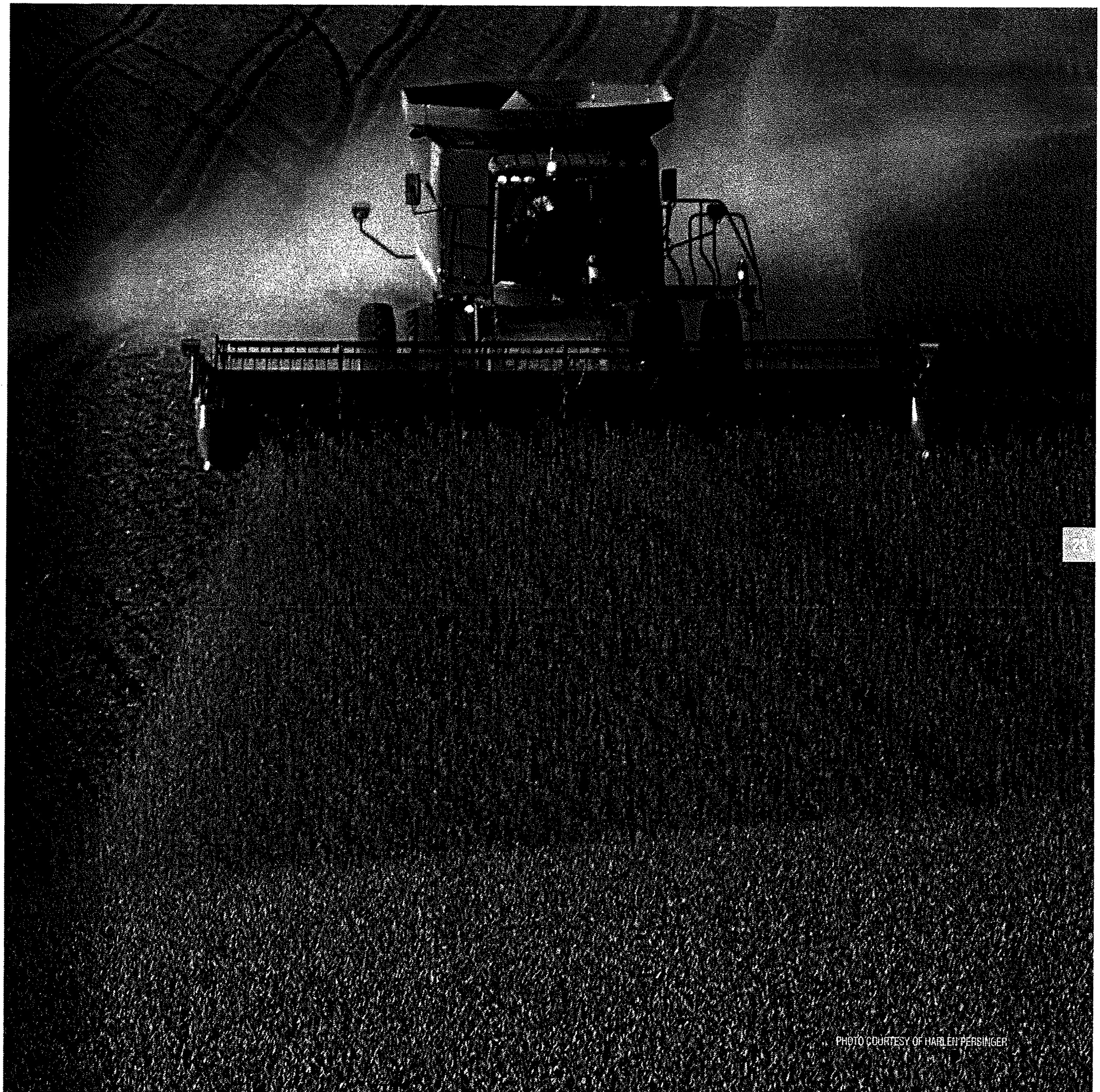
The first generation of those engineered crops have boosted production, reduced pesticide applications by millions of pounds of active ingredients every year, and made it more attractive for growers to adopt no-till and other conservation farming practices that improve soil, water and air quality.

The next generations of bioengineered crops will include production-oriented traits such as improved tolerance to stresses including drought and salinity – vital to growers here and in the developing world – as well as output-oriented traits including better oil and dietary nutrient profiles, and starches suited for high yields of biofuel production.

In all, biotechnology has played a significant role in influencing the shift of millions of acres of U.S. cropland to conservation tillage systems, which in turn has reduced topsoil loss, energy consumption, pesticide use, labor, water pollution and air pollution. Conservation farming systems facilitated by biotech crops also may create opportunities for farmers to generate revenue by providing ecological services to society, sequestering carbon and improving water quality in quickly adoptable and highly cost-effective ways.

The result is improved sustainability, both ecologically and economically, as well as increased production.

Every ton of soil saved on the field, every pound of pesticide that doesn't have to be applied, every extra dollar to help a farmer stay financially viable and – most important – every bushel of yield produced is a milestone in the effort to provide for a global population that steadily continues to increase.



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